Report No. RR-TR-63-7

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WIND, WIND SHEAR AND TURBULENCE REPRESENTATION FOR ATMOSPHERIC BALLISTICS

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U S ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

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WIND, WIND SHEAR AND TURBULENCE REPRESENTATION FOR ATMOSPHERIC BALLISTICS

By

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ABSTRACT

Four topics in wind analysis are briefly discussed. Research endeavors to treat the vertical variation of the wind profile as an entity considering simultaneous occurrences of the wind vector are described. This new approach, the so-called characteristics method, exhibits advantages over other methods.

Profiles with maximum speed values in the frequency distribution of height levels are analyzed and two major types are discussed.

Preliminary results of the investigation of the wind shear parameters as a function of the scale of distance delineate the deficiency of deriving shear parameters from smooth radiosonde records.

The final topic deals with the analysis of the turbulence parameters, and the separation of the wind profile from missile flight recordings into stationary and nonstationary parts.

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance of Messrs. H. Greene and H. Bagley in preparing data for the tables and graphs used in this report.

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I. INTRODUCTION

The general effects of atmospheric elements upon missile flight have been extensively reviewed by Reisig who pointed out the possible effects of the wind upon the missile and on ballistic accuracy. This study will be published as an Army Missile Command report entitled "Significance of Atmospheric Ballistics in Missile Technology." It is the purpose here to concentrate the discussion on the analysis of the wind factor. The analysis will serve to supplement and interpret compilations of wind data such as given in the Climatological Ringbook (Reference 1) or other publications (References 2, 3, and 4).

The four major topics presented in this field of analysis are; (1) the vertical profile, (2) the profiles with maximum wind speeds, (3) the wind shear, and (4) the turbulence parameters.

II. ANALYSIS OF WIND PARAMETERS

A. The Vertical Profile

1. History. In recent years several tabulations of wind data have been published with emphasis on synthetic tabulations (Reference 5), statistical parameters (Reference 6) or frequency distributions at selected levels (Reference 1). The wind profile is generally composed from those tabulations prepared for predetermined altitude levels. This composition disregards simultaneous occurrences in the vertical direction. The vertical relationship is usually restored by considering the correlation coefficients. The limitations of this method were discussed in Reference 7 and necessitated a new approach.

As a first step, mean profiles classified by weather situations were computed for Washington, D. C. as a pilot station (Reference 8). The local weather situation was simply classified by the stream flow in the upper air. At one level, e.g. 1500 meters, 16 points of the compass served as the main grouping which included three subgroups: veering, backing, or constancy from the lower level towards a higher one, e.g. 3000 meters. Thus the 16 profiles of Figures 1 and 2 illustrate the results for Washington, D. C. of mean direction (Figure 1) and speed (Figure 2) when the stream flow between 1500 and 3000 meters remains constant in the summer season. Figures 1 and 2 show a definite difference in the profiles for the various types of weather situations.

The statistical significance of the various profile types depends on the sample size. It is reasonable, that the statistical significance between neighboring weather situations such as Group 3 (east-northeasterly flow) and Group 4 (easterly flow) is small because of the scarcity of data. However, the significance of the difference between Group 4 (easterly flow) and Group 12 (westerly flow) can be established.

Figures 1 and 2 demonstrate that typical profiles may exist. Although the profiles represent mean values composed of computations by levels, the separation into weather situations partially takes into account the vertical relation by reducing the variance and thereby decreasing the departure from the average condition in the individual case.

2. New Method of Approach. The presentation of mean profiles by weather situations was only a first step. A discussion of mathematical analysis of the individual wind profile is given below.

Figure 3 illustrates an average wind profile (direction and speed) as a function of altitude for 1 March 1956 at Washington, D. C. (Silver Hill). Details of the classification process are discussed by the present author in a separate study entitled "On the Mathematical Characteristics of Individual Wind Profiles" which will be published as an AMC report. It is shown in this report that a system of polynomial terms for the direction and the Fourier Series for the speed can adequately characterize the profiles by a few terms. Figure 3, therefore, exemplifies the observed and analytical profile for one case. It is further shown in the report mentioned above, that the coefficients are not independent. Figure 4 displays the polynomial coefficients A_0, A_2 through A_6 by three groups of the linear coefficient A_1. Although the frequency distribution overlaps, three groups can be distinguished easily, and from these, three main types can be derived. Hodographs of the three main types are presented in Figure 5. The hodograph connects the mean wind vector points from level to level. The wind vector at a certain level is obtained by connecting the level point with the origin. The Type A with $A_1 \leq 4.0$ displays backing of the wind with height and Type C with $4.0 \leq A_1$ indicates veering with height. Both types occur mainly during the summer months with veering occurring three times as frequently as backing.

The Type B with A_1 between plus and minus 3.9 represents the winter type with little change of direction with height. The wind speed merely increases up to the jet stream layer and then decreases towards 20 km with slight increase above that height.

The grouping into three major types reveals no new principles and serves as a first survey only. It indicates, however, that the classification is based on a sound climatological background.

3. One Example of Application. The derived coefficients can serve as the initial material for making further investigations. One example of an application is presented in this section. Figures 6 and 7 show comparisons of wind profile representations by several methods using the 25 January 1952 profile for Patrick AFB as a test case. The mean profiles computed for the zonal (Figure 6) and meridional (Figure 7) components are obviously inadequate in this case. The profiles computed by the correlation method exhibit some improvement. In this method, which was first introduced by Court (Reference 2), the inter- and intralevel linear coefficients are used. It should be noted that the present

example constitutes an ideal case for the correlation method because the departure from the mean value of 12 km assumes an extreme, and therefore the maximum achievement of the correlation method should appear. In addition, it has been shown (Reference 7) that the correlation method works best when utilizing a known wind velocity in the jet stream layer (Table I).

The example presented in Figures 6 and 7 indicates that the corrections applied to the mean profile by the correlation method reduce the differences between the observed and analytical profiles. The mean squared differences between mean profile and observed profile are reduced to approximately one-half the amount in this individual case. If the characteristics method described above is used, the differences between observed and analytical profile are further reduced to approximately 10 per cent (Table I). The calculations for this example were based on only two polynomial terms and one Fourier term, so that further improvement is possible, as the potential of the characteristics method is not fully utilized.

Table I shows that although the example in Figures 6 and 7 comprises only a single case, the results are representative for even an extended sample. Several cases were selected and are described in detail in Reference 7. The details may not be repeated here. Two summaries, mean conditions as well as extreme conditions, were combined. The wind parameter to be known at a selected level served as the basis for the correlation method. Three levels were chosen; namely, 3 km near the ground, 12 km around the jet stream layer, and 20 km in the lower stratosphere. The figures of Table I are not definitive insofar as to be representative of the month of January for Patrick AFB, but may be used to compare three different methods under equal assumptions and unknowns.

Part A of Table I shows the mean squared difference between the analytical and observed profile. This difference has arbitrarily been set at 100 per cent utilizing the monthly mean of January. As shown in the table, the correlation method works best using known parameters taken from the jet stream layer, with reduction of the difference to 67 per cent. By using a known wind velocity in the lower troposphere (3 km level) only a 12 per cent decrease is obtained. Knowledge of the wind velocity in the lower stratosphere (20 km) is of little value.

Utilization of the wind velocity in the jet stream layer, in addition to its possible relationship with the wind profile, eliminates one difference between the observed and analytical profile, which represents a large contribution to the mean squared difference. Selecting parameters in the lower troposphere, this item remains in the summation and the reduction is less. Obviously, the relationship between lower stratospheric parameters and the troposphere cannot be truly reflected in the linear correlation because its representation of mean conditions may obscure the typical features of the individual profile.

Table I

SUMMARY OF COMPARISON BETWEEN MONTHLY MEAN PROFILE (MM) CORRELATION (CO) AND CHARACTERISTICS (CHA) METHOD

a. Mean Square Difference ($\bar{D}$)

Level Selection		n	MM	CO	CHA	NOWI
3km	Mean square difference	17	156	137	105 (90)	693 m/sec^{-}
	Percentage	-	100	88	67 (58)	444%
12km	Mean square difference	15	187	126	101 (87)	788 m/sec^{-}
	Percentage	-	100	67	54 (46)	420%
20km	Mean square difference	29	152	149	106 (98)	553 m/sec^{-}
	Percentage	-	100	98	70 (65)	365%

b. Mean Integral Difference Per Profile (D_{int})

Level Selection		n	MM	CO	CHA	NOWI
3km	Integral difference	17	3.7	3.1	2.2 (1.8)	11.4 m/sec^{-}
	Percentage	-	100	85	60 (50)	308%
12km	Integral difference	15	3.3	2.2	1.6 (1.5)	11.5 m/sec^{-}
	Percentage	-	100	67	49 (45)	345%
20km	Integral difference	29	3.7	3.6	2.8 (2.7)	10.5 m/sec^{-}
	Percentage	-	100	97	77 (73)	287%

NOTE: The last column indicates the difference by assumption of no wind (NOWI).

This latter conclusion is further affirmed by applying the characteristics method. Not only are all differences lower than those obtained with the correlation method, but a reduction of the initial difference between observed and mean profile is obtained whether parameters are assumed in the lower troposphere or in the stratosphere. These results are shown in the first column of Table I under CHA. It should be emphasized that by grouping and utilizing mean coefficients, the observed value is not completely reached in the analytical profile at the parameter selection level, e.g. 12 km, although this value would be known by observation. Thus, the decrease to 54 per cent in the 12 km level selection is even more significant as it does not result from knowledge of the wind velocity at that level.

The same grouping was used for the characteristics methods as was used for the correlation method. Inspection of the coefficients revealed, however, that two or three subtypes of profiles were involved. This recognition of heterogeneity of the selected sample was not possible by the correlation method. Incorporating this information further decreased the differences as shown in parentheses in the second column under CHA.

Part A of Table I presents the squared differences. Since it may be argued that the squared difference is unimportant and that the integral effect of the profile is the essential component, Part B of Table I has been assembled to account for the integral effect. This information shows that the same conclusions can be drawn for the mean integral differences as were obtained for the squared differences. Thus the application of the characteristics method may be advantageous in many problems.

B. Profiles with Maximum Speed of an Altitude Level

The previous section stressed the consideration of the wind profile and its variation with height as an entity. Average profiles generally do not create problems in missile applications; difficulties arise when extreme conditions prevail. Of particular interest are profiles in which the wind speed assumes the extreme values in the frequency distribution of an altitude level (level extremes). Two typical examples will be discussed.

Two profiles for Washington, D. C. (Silver Hill) are shown in Figure 8, one for 6 January 1957 at 21^h GMT and one for 25 January at 0^h GMT. Both profiles have level extremes. On 6 January the extreme wind speed of the 9 km level from the period 1956 to 1961 for the months of January appeared. The 25 January profile constitutes the case with the extreme wind speed at the 10 km level. The two profiles demonstrate an important difference between the vertical variation. The 25 January speed profile from 4 km through the top of the ascent at 15 km displays values which fall into the group exceeding the 97.5 per cent probability threshold of the accumulative frequency distribution of the respective level. This means that for a sequence of levels the wind speed remains extremely strong compared with the level frequency. This is illustrated in Figure 8 with the abscissa scale given in percentage of the accumulated level frequency distribution. Since the values over 90 per cent are of particular interest, that part of the abscissa between 90 and 100 per cent was enlarged in the figure.

The second profile of 6 January exhibits a different feature. Only within a small altitude range around 9 km does the wind speed assume strong values (compared with the level frequency), while for the remaining part of the profile the wind speed resembles average conditions.

The two profiles create two different conditions for the wind shear as demonstrated in Figure 9. This figure exhibits the 1 km wind shear values for the two profiles, and also the vector wind shear for a synthetic profile connecting the 98 per cent probability thresholds of the accumulated frequency distributions from level to level (References 1 and 5). The 99 per cent probability threshold for the accumulated frequency distribution of 1 km vector shear values (Reference 1) is also displayed.

Figure 9 shows that the 25 January profile follows closely the wind shear of the 98 per cent synthetic profile. The profile with serious shear upon missile design is the wind shear profile for 6 January. This profile reaches the 99 per cent vector shear value of the respective level frequency distribution around the level of maximum wind speed.

The examples presented here indicate that for a complete analysis both wind speed and shear should be considered. For example, a profile with strong winds throughout several consecutive layers may affect the displacement considerably, but its influence upon stability and control may prove to be negligible. The drift effect, on the other hand, may be only of minor importance in the second type of profile, while the existence of strong shear values around the maximum wind of the profile may create serious difficulties with stability and control. This topic is being analyzed further.

C. The Wind Shear Parameters

The relation between wind shear and wind speed was discussed briefly in the previous section. Instrumentation for measuring wind shear is still incomplete. The common instrumentation of the radiosonde does not permit the derivation of shear values for all interval sizes, and the frequency distribution of the wind shear parameter depends on the scale of distance (Table II).

Mean Vector Shear, Standard Deviation and Extreme Values are given in Table II for four distance intervals and three altitude ranges. The data are derived from missile flight recordings (angle of attack method by Reisig, Reference 9) taken on 4 February 1960 and should be considered as preliminary examples from one ascent. However, they demonstrate typical

Table II

MEAN VECTOR SHEAR, STANDARD DEVIATION AND EXTREME VECTOR SHEAR FOR SEVERAL SCALE DISTANCES, DERIVED FROM MISSILE FLIGHT RECORDINGS OF 4 FEBRUARY 1960

(Values Reduced to Unit $\frac{1}{sec}$)

	0.4 - 1 km	1 - 3 km	3 - 10 km
Distance interval, m	Mean Vector Shear		
12	.011	.022	--
24	.012	.019	.023
48	.010	.017	.019
96	--	.010	.014
	Standard Deviation		
12	.0086	.035	--
24	.0068	.024	.025
48	.0068	.016	.017
96	--	.006	.009
	Extreme Values (Reduced)		
12	.033	.284	--
24	.030	.153	.233
48	.027	.106	.112
96	.023	.027	.057
	Extreme Values, Per Distance (m/sec per interval)		
12	.40	3.41	--
24	.72	3.66	5.59
48	1.31	5.11	5.39
96	2.19	2.63	5.49

features of the problem. The results are reduced to the unit $\frac{1}{sec}$ for comparison purposes.

Inspection of Table II shows that the mean vector shear decreases with increasing distance interval for the altitude ranges 1 to 3 and 3 to 10 km. The values in the 0.4 to 1 km height range comprise a small sample size and may be subjected to sampling errors. They could also indicate the dominant frictional system in the ground layer.

The decrease of the mean shear vector with increasing distance interval indicates that shear vectors should not be presented in the unit $\frac{1}{sec}$ but rather in m/sec per scale interval; the interval from which the data are derived should always be given. The example in Table II shows that for the altitude range 1 to 3 km the average vector shear would be $\frac{0.9 \text{ m/sec}}{96 \text{ m}}$. Based on this figure, $\frac{0.12 \text{ m/sec}}{12 \text{ m}}$ might be assumed to be the average vector shear for the 12 m interval. However, as can be seen in Table II, the average derived from observed data is $\frac{0.26 \text{ m/sec}}{12 \text{ m}}$ which is double the above postulated size. Consequently, shear data compiled from radiosonde records computed from 1 km intervals must be interpreted with caution. Not only are the data smoothed by the effect, which the balloon of the radiosonde creates, but also by the diminutive effect of the scale of distance.

The standard deviation, like the average vector shear, increases with intervals of distance. The expansion of the standard deviation, however, is about twice that of the mean vector shear. This implies that the extreme values approximate the same magnitude per interval distance. For example, in the 3 to 10 km altitude range, the extreme shear is around 5.5 m/sec per interval whether related to the 24, 48, or 96 m interval. In the 0.4 to 1 km altitude range (frictional ground layer), the relative increase of the extremes is smaller than the one for the scale of distance. This is shown in Table II under reduced values. Thus the absolute extremes diminish with decreasing scale of distance.

The contents of Table II indicate the necessity of detailed investigations on the validity of shear values compiled by utilizing ordinary radiosonde data and of investigating the relation between the wind shear vector and the scale of distance in the free atmosphere. Further results have been presented in the second Conference on Climatology (Reference 4).

D. Turbulence Parameters

Knowledge of turbulence parameters in the atmosphere above ground level is still very limited. Recordings gathered by instrumentation attached to airplanes and pilot reports may yield sufficient information for aviation problems, but this application to missile problems seems doubtful. While the airplane is concerned with disturbances of the mean flow affecting the horizontal movement, a missile is principally influenced by disturbances acting on the vertical motion of the missile and stability.

Analysis of missile flight records is one way to obtain some insight into the problem. Investigations of turbulent motion from these missile flight records are more difficult because a constant stationary wind value cannot be assumed as it can in a time series where the time average is postulated as the stationary part.

The wind profile varies with height and a stationary wind profile, variable with height, must be derived. Separating the missile flight records into stationary and nonstationary parts is discussed in Reference 3. Figures 10, 11, and 12 illustrate the separation for data of 24, 48, and 96 m observational intervals, respectively. The method presented in Reference 3 has been slightly modified to guarantee smoother transition between the joints of the 23-points sections.

The first profile on the left side of Figures 10 through 12 represents the recorded profile (solid line) while the dotted line indicates the mean profile. Note that 24 m observational intervals range from surface through 10 km, 48 m intervals through 30 km, and 96 m intervals through 50 km. Thus the impression of increasing amplitude with interval distance is due to increase of the variations with height.

The 24 m interval shows some irregular variations of smaller amplitude except around 2 and 6 km. Figure 11 (48 m interval) shows that the mean profile is smoother due to the increase in interval distance from 24 to 48 m. The instability at 2 km is still observed; the one around 6 km is missing and explained by the fact that the instability at 6 km was weaker than the 2 km variation. By increasing the interval distance the other fluctuations assume the same magnitude and the fluctuation at 6 km is no longer observed.

In Figure 11 new important variations appear around 14 km and subsequently at high altitudes. The larger variation around 14 km, located above the layer of maximum wind, deserves special mention. Information on the turbulent motion below the jet layer, which cannot be observed in the present example, is given in Reference 10.

Figure 12 displays the 96 m interval analysis. Again, the mean profile (stationary part) looks smoother than in the 48 m interval analysis, but still contains all the essential features of the preceding mean profiles of smaller scale intervals. Instability of the area around 14 km can again be identified. Similar large fluctuations repeat at higher altitudes.

The analysis presented contains peak amplitudes around 4 m/sec for the 24 m interval, and 8 m/sec for the 96 m interval analysis. This seems to be a relatively moderate fluctuation. It should be emphasized, however, that the missile firing which is analyzed here was not for the purpose of recording extreme turbulence conditions, but rather for other test purposes. Thus it can be assumed that only average conditions are presented. In addition, Patrick Air Force Base, where the flight occurred, may have rather placid wind conditions. Further, the wind speed displayed here is only one part of the fluctuation. Total variations, including the wind direction, are presented later.

The increase of the variations with height should be considered. Although an overall increase of the oscillation may be due to the instrumentation, the sporadic increase at certain altitude intervals may be attributed to turbulent flow or instability of the air.

Figures 10 through 12 constitute a first example to demonstrate the fluctuation of the wind with height. The fluctuation is similar to the well-known time variation of the wind at the surface which can be observed for any part of unsmoothed wind recordings. The variation length, mixing length, and possible eddy size should be further investigated.

III. CONCLUSIONS

Four topics in wind analysis have been discussed; (1) the representation of the variation of the wind profile with altitude as an entity, (2) profiles of maximum speed, (3) wind shear, and (4) turbulence.

The present standard practice is to compose the wind profile by utilizing values extracted from level frequency distributions. Thus the simultaneous occurrence of the wind vector in the vertical profile is largely neglected. The separation into weather situations (Figures 1 and 2) considers only partially a simultaneous occurrence with height and indicates that this area should be further analyzed.

Description characteristics for wind profiles have been developed. A system of representing wind direction and speed by polynomial and Fourier coefficients, respectively, has been discussed briefly. An application of this method was demonstrated (Table I) and exhibits advantages over other existing methods. First climatological results are given showing three mean profile types for Washington, D. C. (Figure 5).

The problem of analyzing the wind profile involves the study of profiles with maximum wind speed. Such profiles can be expected to have the largest effect on missile stability and control. The analysis showed that mainly two types of maximum wind speed profiles exist. In the first type, the profile assumes maximum level wind speeds through several levels. The second type reaches the maximum level wind speed for a small altitude range of a few levels only. However, the latter type are those in which the wind shear parameter usually causes considerable effect on stability and control.

The wind shear parameter is a function of the distance scale. Frequency distributions of wind shear derived from smooth radiosonde records of 1 km intervals do not represent the true distribution for smaller intervals. The derivation of smaller scale shear values from tabulations of larger scale intervals yields values that are too small, if no consideration is given to the enlargement factor. An example is given in Table II.

The turbulence parameters (perturbation functions for stability and control, eddy size, mixing length, etc.) in the free atmosphere are only slightly known. Analysis of missile flight recordings has begun in order to provide some insight into the problem. Examples of separated stationary and nonstationary parts of the profile are presented at 24, 48, and 96 m intervals. It appears that larger irregular fluctuations of the nature of instabilities or turbulence exist in limited layers, and that, in general, the amplitude of the oscillations increases with height.

It is obvious that this report does not cover all of the topics on wind analysis. The purpose is merely to outline certain topics of research and to present some first results of the investigations.

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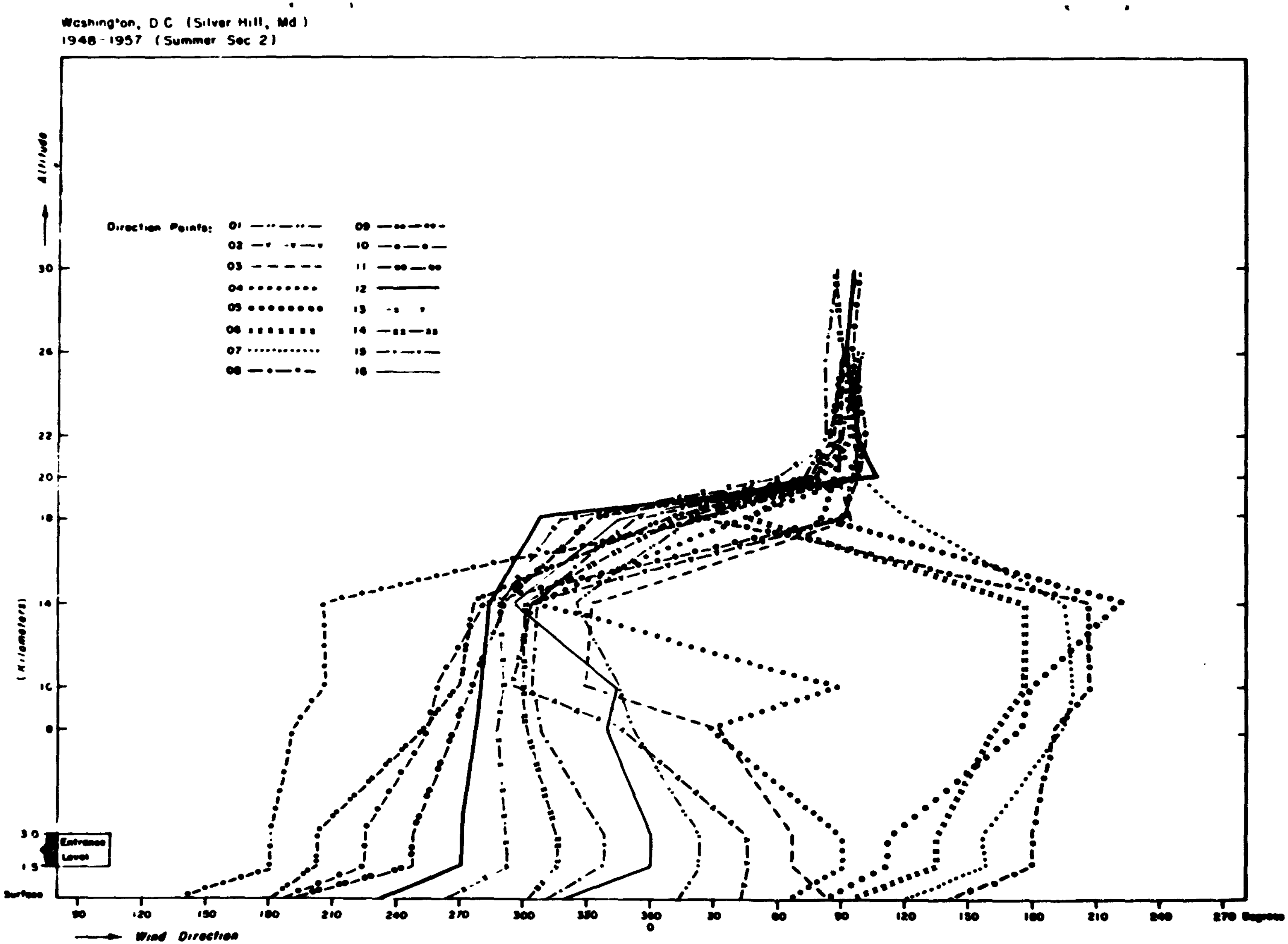

Figure 1. MEAN WIND DIRECTION PROFILES FOR WEATHER SITUATIONS (AIR FLOW BETWEEN 1500 AND 3000 m IN 16 POINTS OF THE COMPASS) AT WASHINGTON, D. C. (SILVER HILL).

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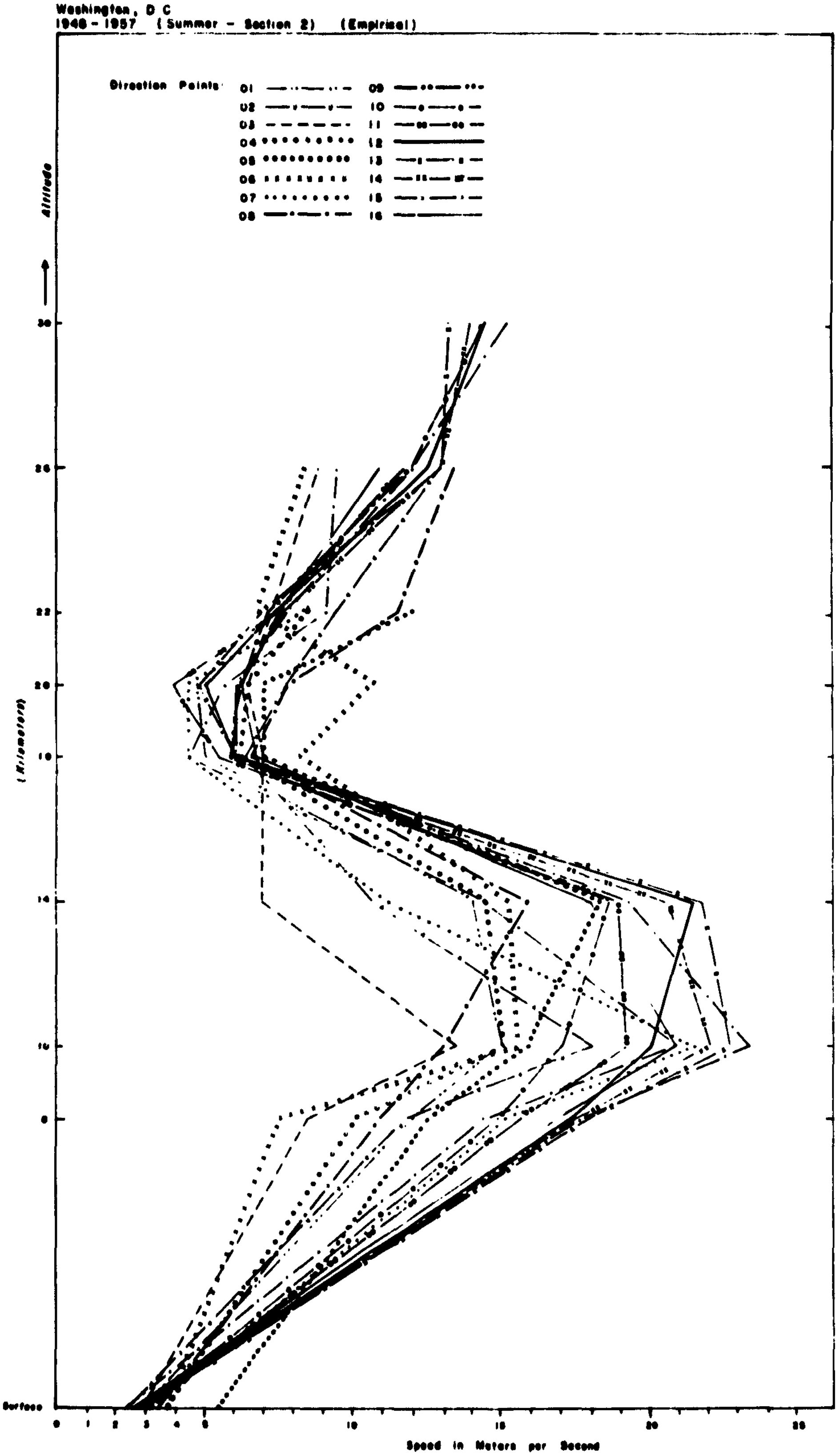

Figure 2. MEAN WIND SPEED PROFILES FOR WEATHER SITUATIONS (AIR FLOW BETWEEN 1500 AND 3000 m IN 16 POINTS OF THE COMPASS) AT WASHINGTON, D. C. (SILVER HILL).

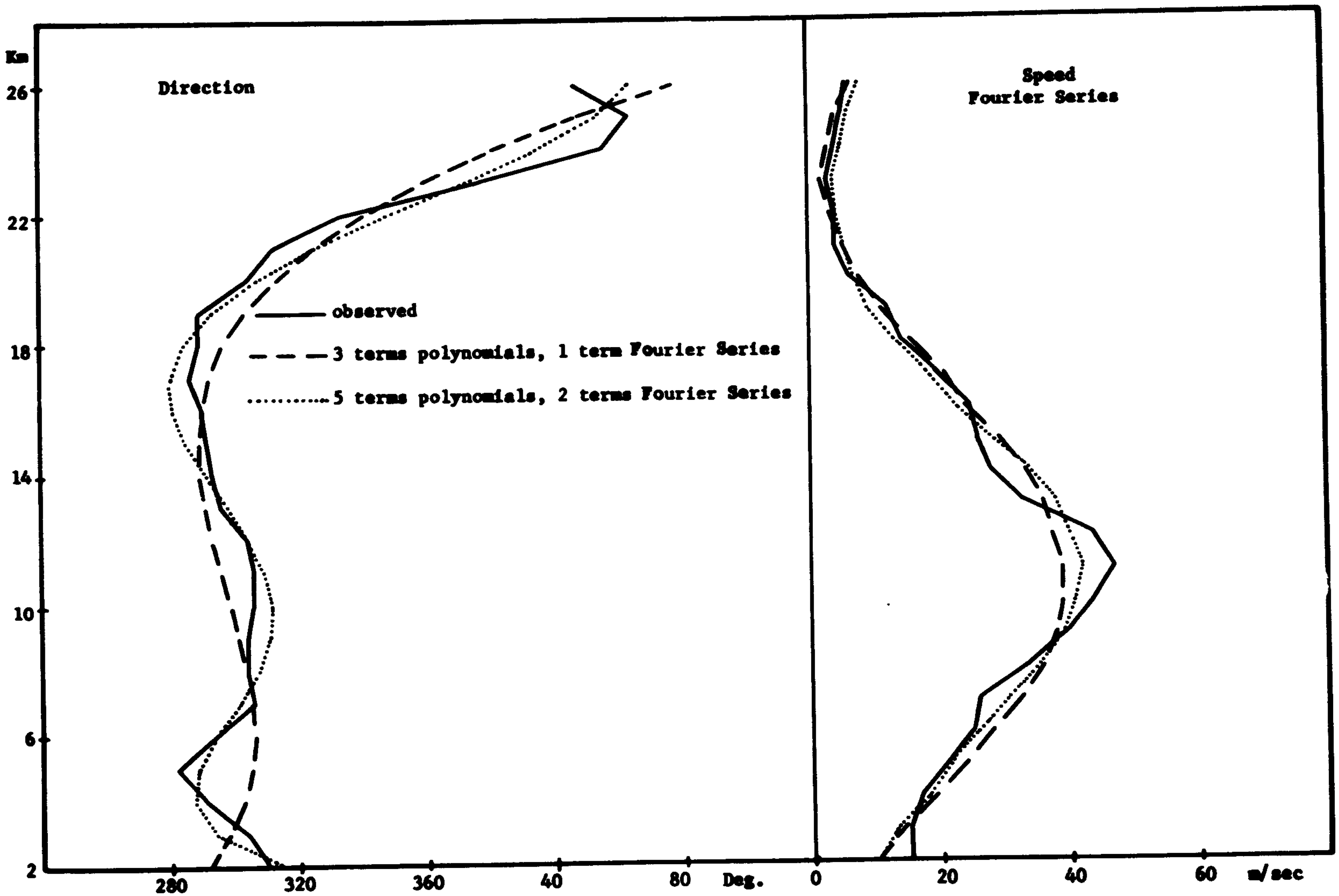

Figure 3. REPRESENTATION OF THE WIND PROFILE BY POLYNOMIAL TERMS (DIRECTION) AND FOURIER SERIES (SPEED) FOR 1 MARCH 1956 AT WASHINGTON, D. C. (SILVER HILL).

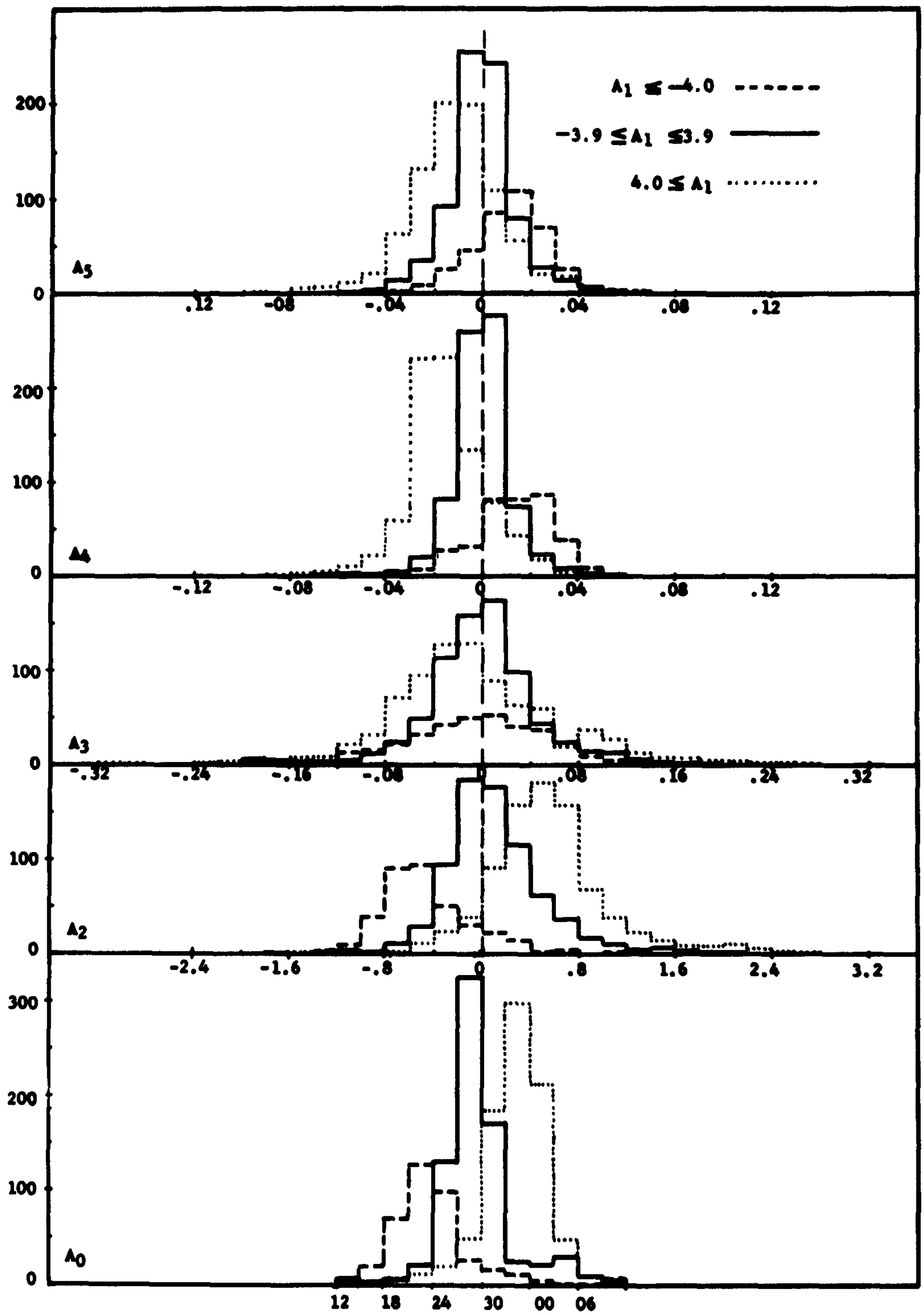

Figure 4. FREQUENCY DISTRIBUTION OF POLYNOMIAL COEFFICIENTS BY THREE GROUPS OF A_1 (LINEAR TERM) FOR PROFILE ANALYSIS 2 TO 26 km AT WASHINGTON, D. C. (SILVER HILL). PERIOD OF RECORD 1955 TO 1959.

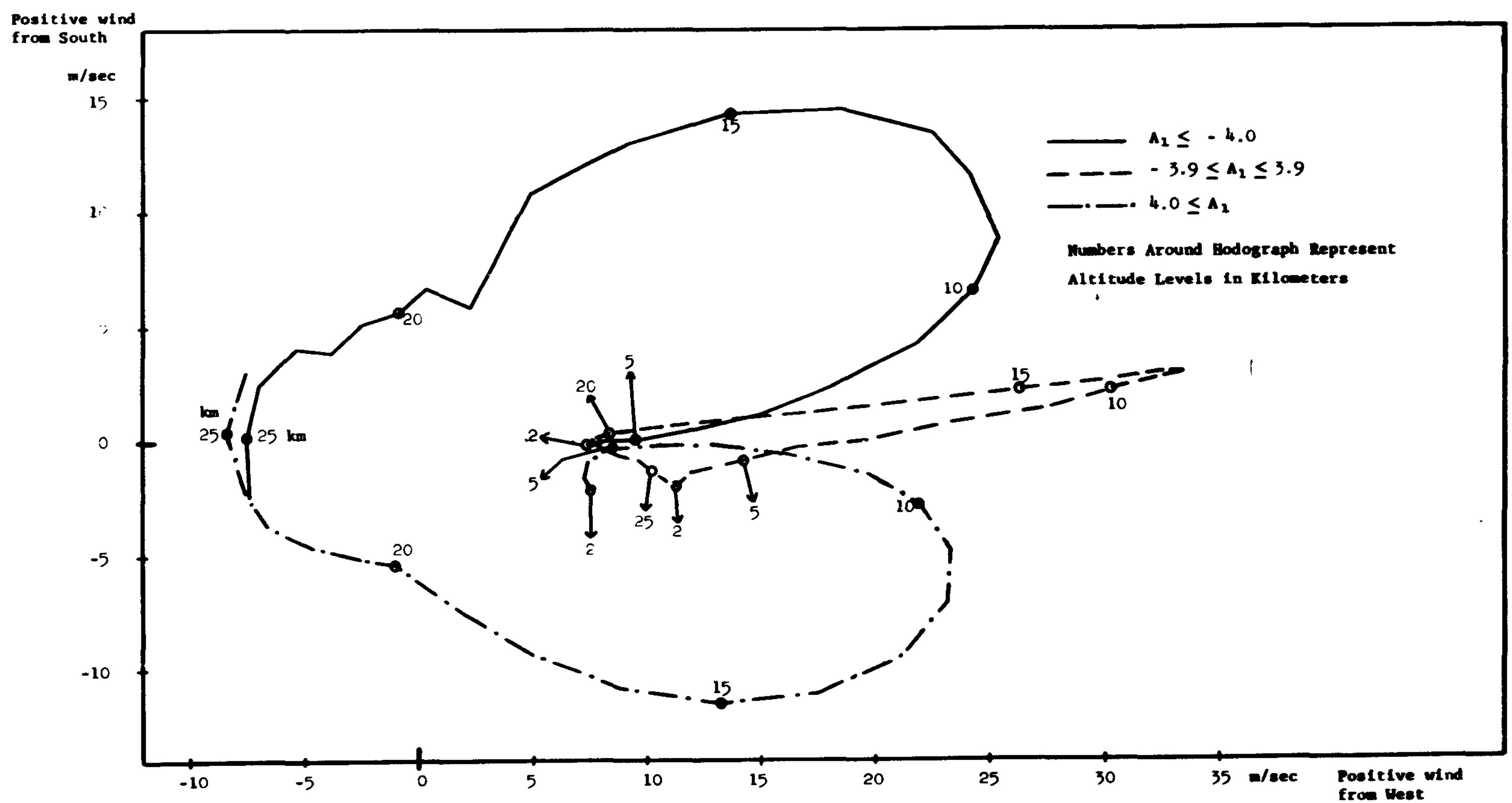

Figure 5. HODOGRAPH REPRESENTATION OF THREE PROFILE TYPES FOR WASHINGTON, D. C. (SILVER HILL).

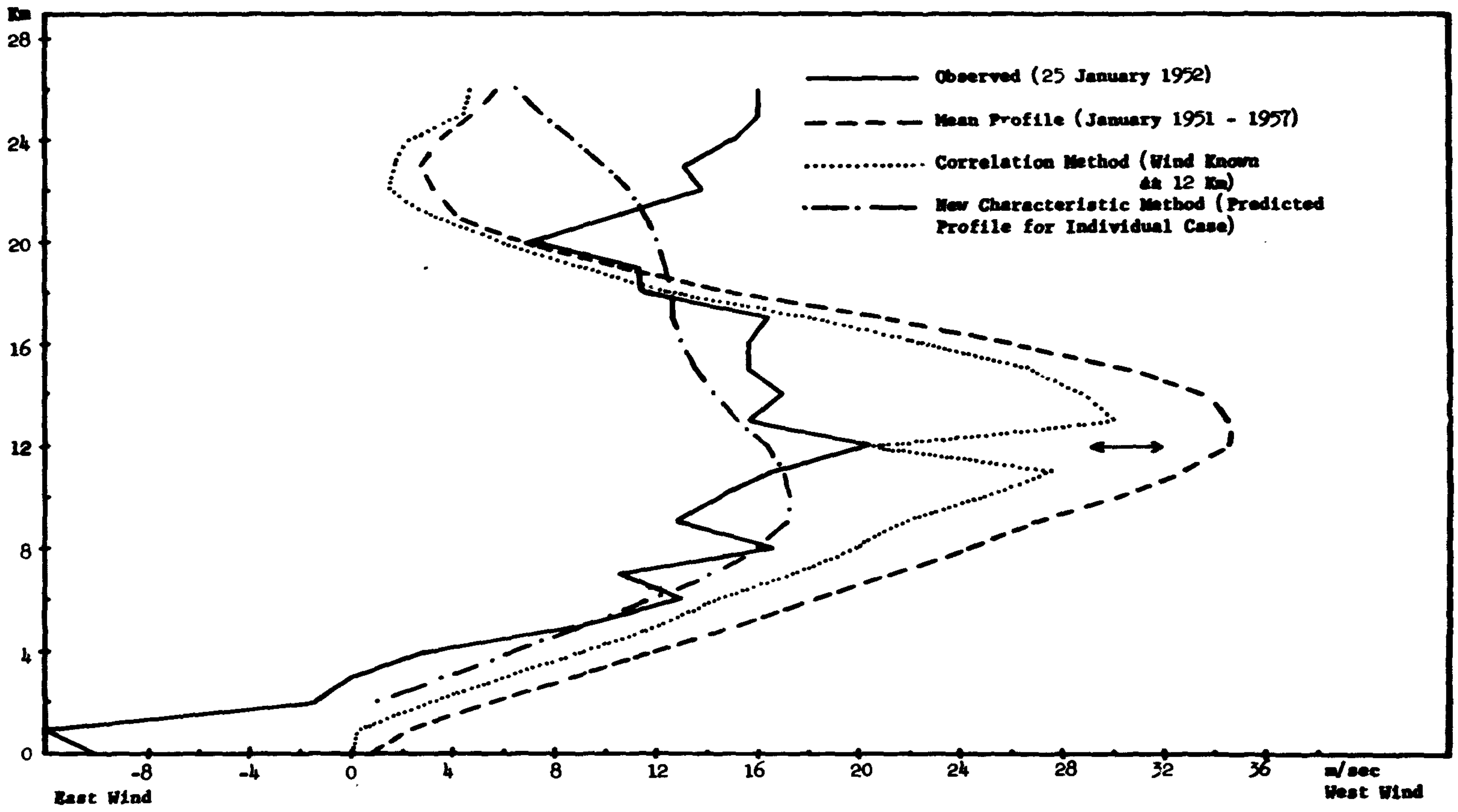

Figure 6. ZONAL WIND COMPONENT FOR PATRICK AFB IN JANUARY FOR SEVERAL PREDICTION METHODS.

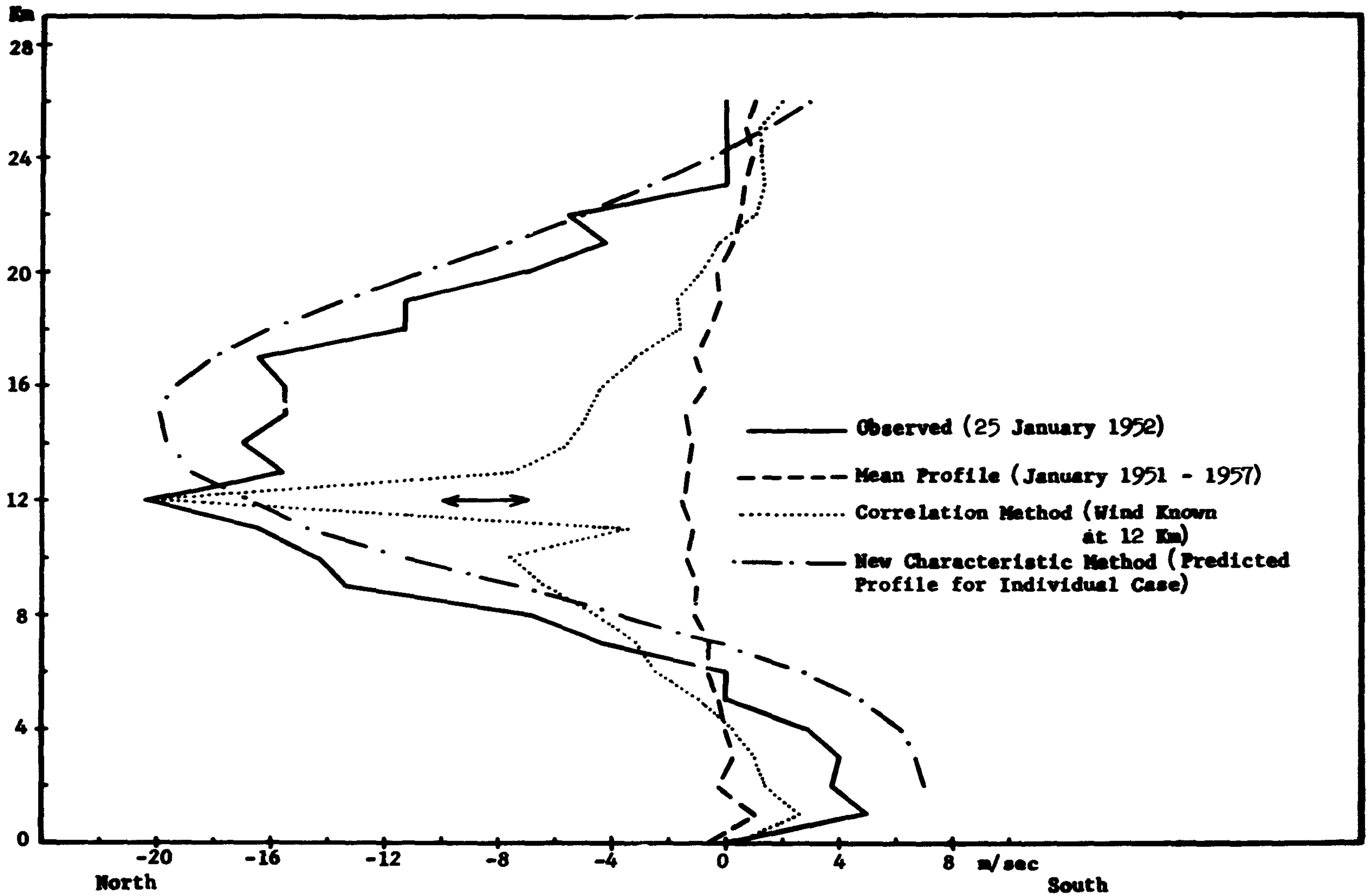

Figure 7. MERIDIONAL WIND COMPONENT PROFILES FOR WEATHER SITUATIONS (AIR FLOW BETWEEN 1500 AND 3000 m IN 16 POINTS OF THE COMPASS) AT WASHINGTON, D. C. (SILVER HILL).

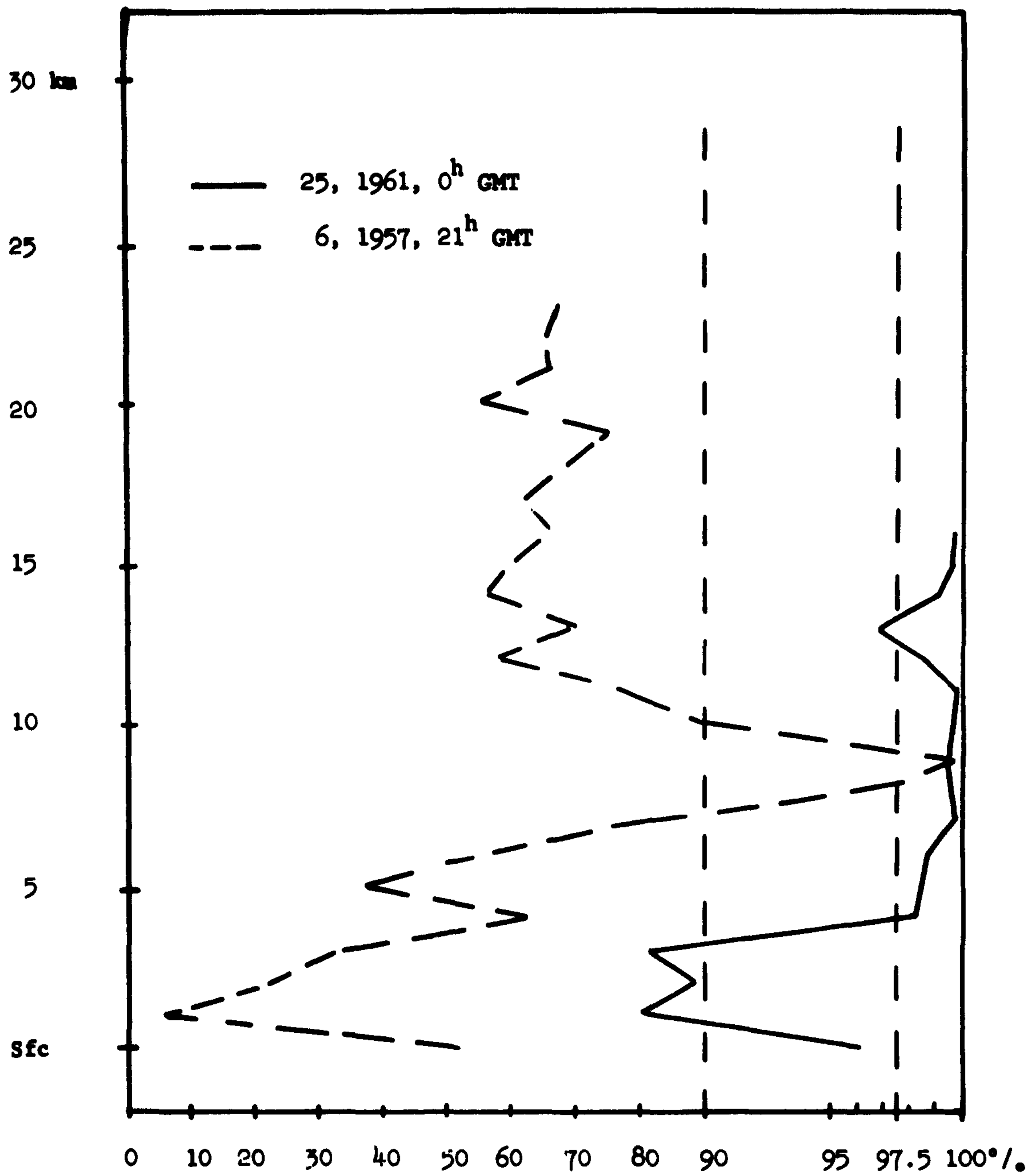

Figure 8. WIND PROFILES WITH MAXIMUM SCALAR WIND SPEED AT 9 AND 10 km ALTITUDE AT WASHINGTON, D. C. (SILVER HILL) DURING JANUARY 1956 TO 1961.

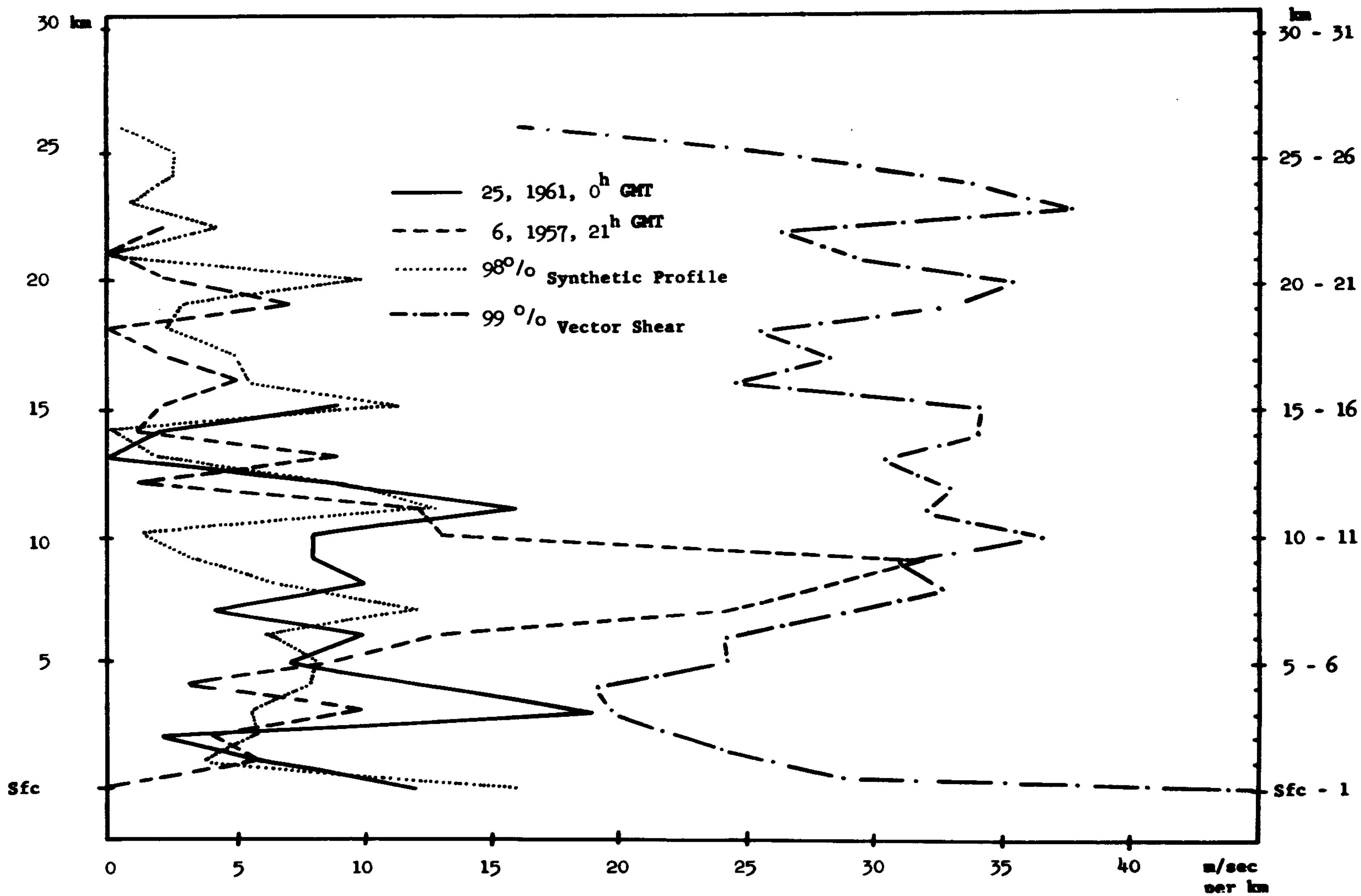

Figure 9. WIND SHEAR PROFILES AT WASHINGTON, D. C. (SILVER HILL) FROM PERIOD JANUARY 1956 TO 1961.

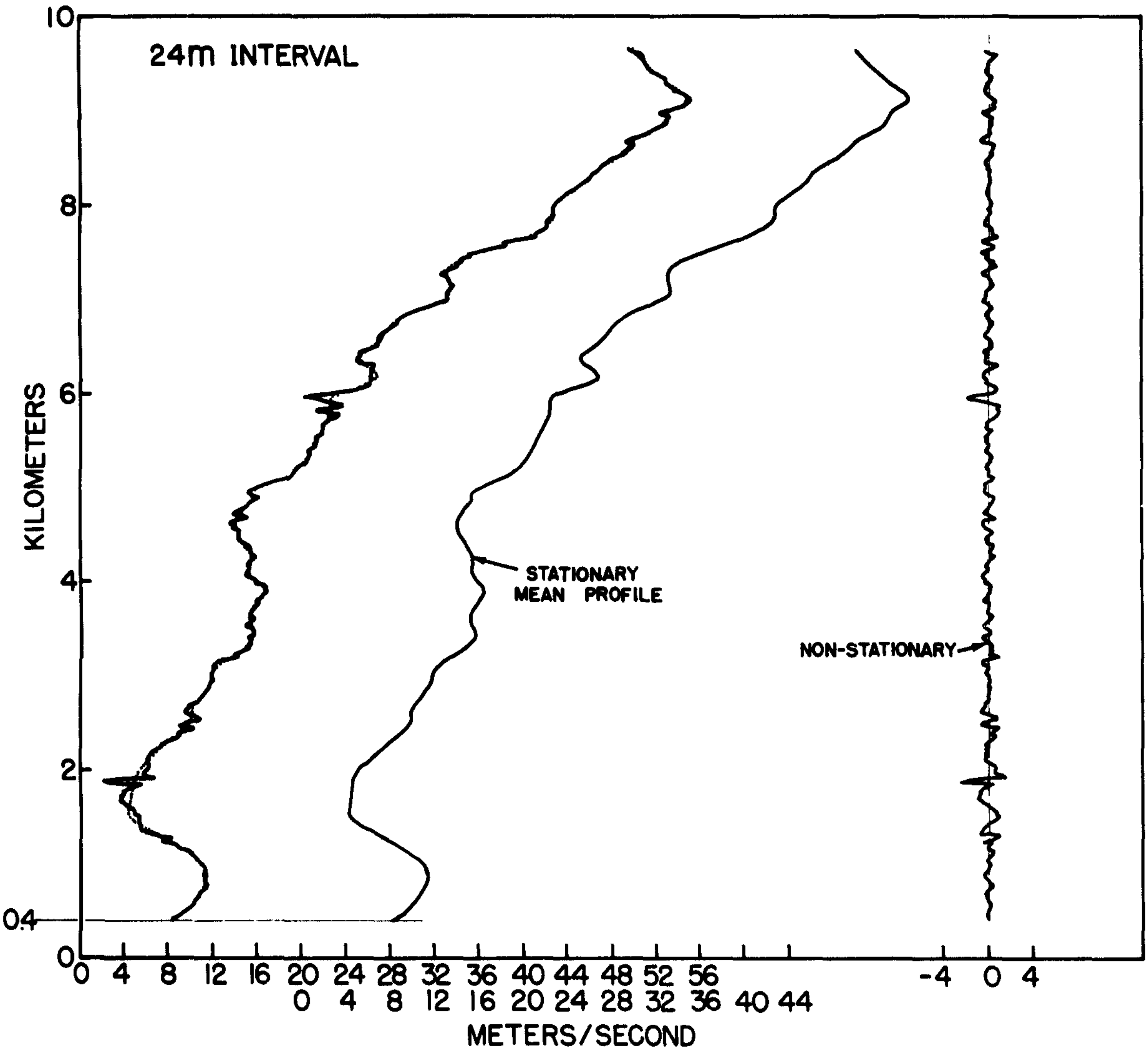

Figure 10. SEPARATION OF THE OBSERVED PROFILE INTO STATIONARY AND NONSTATIONARY PART FOR MISSILE FLIGHT DATA OF 4 FEBRUARY 1960, 24 m INTERVAL DISTANCE OF THE OBSERVATIONS.

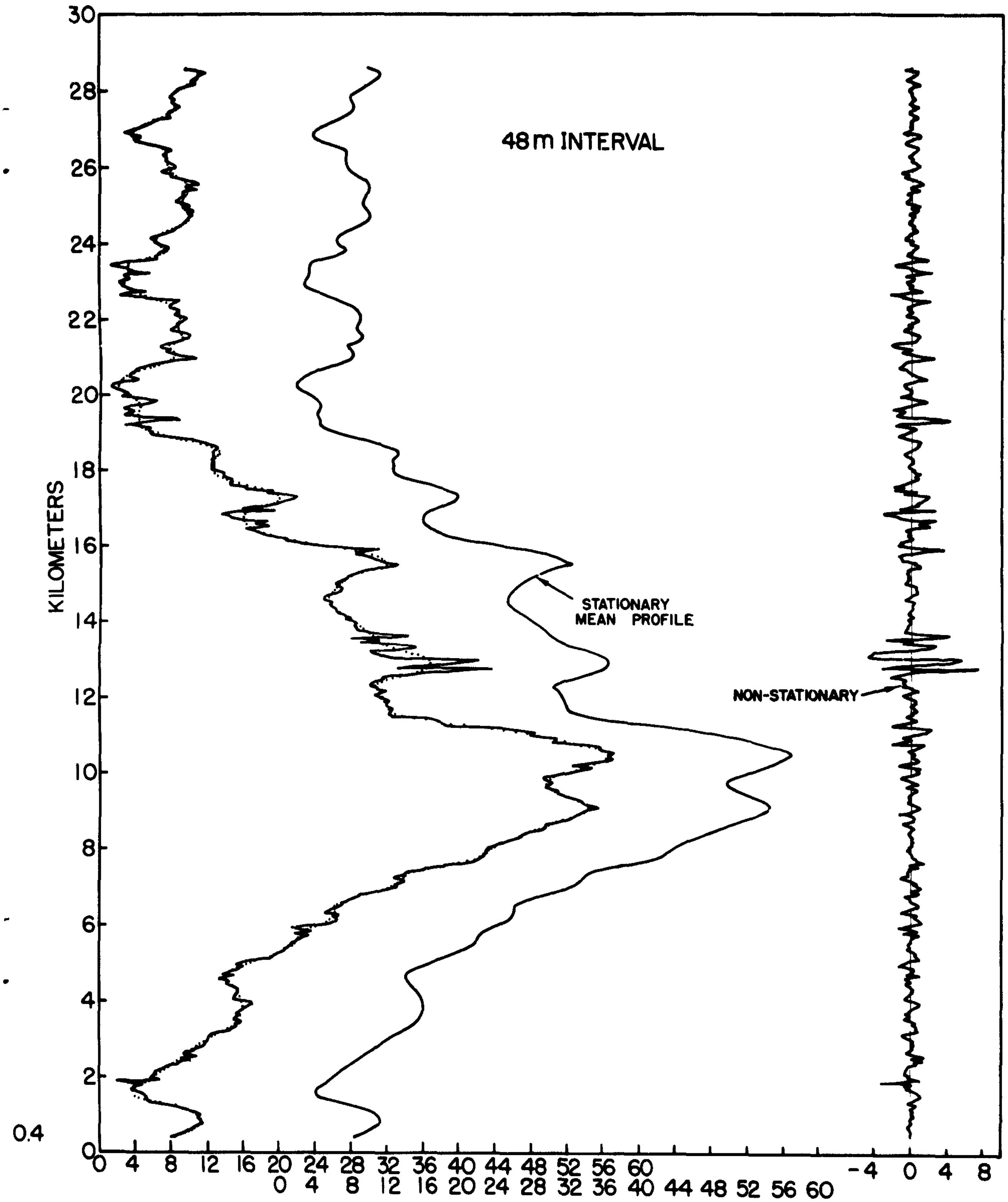

Figure 11. SEPARATION OF THE OBSERVED PROFILE INTO STATIONARY AND NONSTATIONARY PART FOR MISSILE FLIGHT DATA OF 4 FEBRUARY 1960, 48 m INTERVAL DISTANCE OF THE OBSERVATIONS.

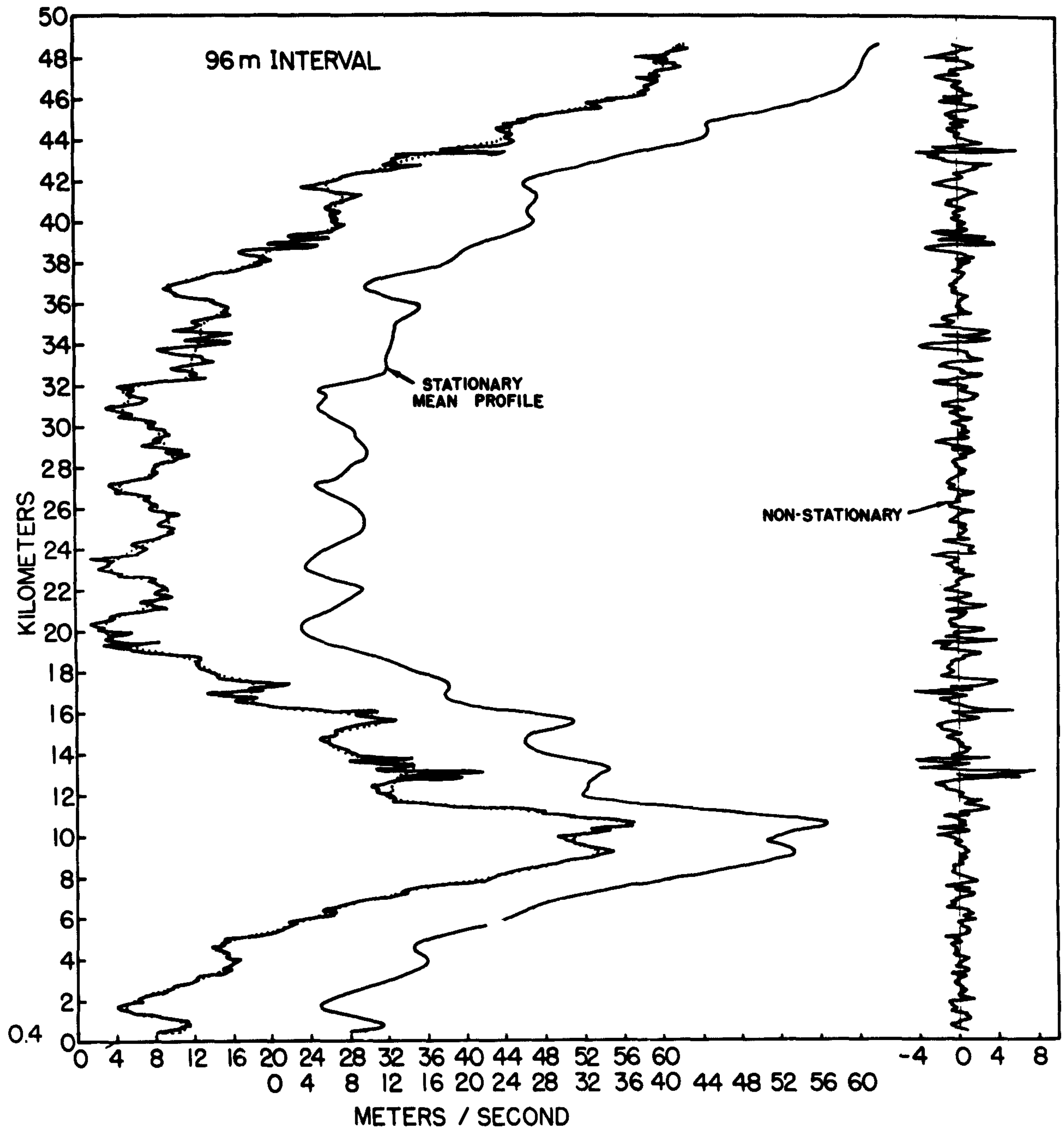

Figure 12. SEPARATION OF THE OBSERVED PROFILE INTO STATIONARY AND NONSTATIONARY PART FOR MISSILE FLIGHT DATA OF 4 FEBRUARY 1960, 96 m INTERVAL DISTANCE OF THE OBSERVATIONS.

1 April 1963 Report No. RR-TR-63-7

APPROVED:

Norman M. Shapiro

for J. P. HALLOWES, JR.
Director, Physical Sciences Laboratory

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The purpose of this report is to present an analysis of the effect of wind on atmospheric ballistics. The analysis will supplement and interpret compilations of wind data such as given in the Climatological Ringbook. The four major topics of the analysis are: the vertical profile; the profiles with maximum wind speeds; the wind shear; and the turbulence parameters.

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